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CRYOGENIC MONOCRYSTALLINE OPTICAL CAVITY FOR LASER STABILIZATION AND PRECISE TIME MEASUREMENTS

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FINAL REPORT
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The purpose of this three-year project was to test the feasibility of stabilizing the frequency of a laser by locking it to a resonance of a cryogenic Fabry-Perot optical cavity. The resonant frequencies of a Fabry-Perot cavity are precisely determined by its dimensions, and the use of low-expansivity materials offers the prospect of arbitrarily low drift rates in the cavity dimensions at low enough temperatures. Advances in materials processing motivated by the semiconductor industry have provided a supply of high-purity, low-expansivity materials available in monocrystalline form. Silicon appears to have a thermal expansion coefficient lower than most other materials below 5 K. Thus, we obtained a 1.6 kg single crystal of silicon from which a reference cavity was made.

Our first experiment consisted of locking a helium-neon laser to the silicon cavity at liquid helium temperatures. During the cooldown, the thermal expansion coefficient of the silicon was measured, and below 8 K an upper limit was found to be $5 \times 10^{-9}\ K^{-1}$. At low temperatures, the laser frequency tracked the cavity resonance with an error of ~10 Hz/√Hz, which was equal to its room temperature performance. Appendix A describes this experiment in detail.

Improvements in performance are possible by using higher-reflectivity mirrors. The silicon cavity has a finesse of 300 corresponding to a mirror reflectivity of 99.0%. "Supermirrors" are available which have reflectivities of 99.99% or better, corresponding to a cavity finesse in the tens of thousands. However, the low temperature behavior of the finesse was unknown, so we undertook to measure it directly. We cooled a supermirror